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NASA Lewis Research Center's Preheated Combustor and Materials Test Facility

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NASA LEWIS RESEARCH CENTER'S PREHEATED COMBUSTOR AND MATERIALS TEST FACILITY

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SUMMARY

The Preheated Combustor and Materials Test Facility (PCMTF) in the Engine Research Building (ERB) at the NASA Lewis Research Center is one of two unique combustor facilities that provide a nonvitiated air supply to two test stands, where the air can be used for research combustor testing and high-temperature materials testing. Stand A is used as a research combustor stand, whereas stand B is used for cyclic and survivability tests of aerospace materials at high temperatures. Both stands can accommodate in-house and private industry research programs.

The PCMTF is capable of providing up to 30 lb/s (pps) of nonvitiated, 450-psig combustion air at temperatures ranging from 850 to 1150 °F. A 5000-gal tank located outdoors adjacent to the test facility can provide jet fuel at a pressure of 900 psig and a flow rate of 11 gal/min (gpm). Gaseous hydrogen from a 70 000-ft³ (CF) tuber is also available as a fuel.

Approximately 500 gpm of cooling water cools the research hardware and exhaust gases. Such cooling is necessary because the air stream reaches temperatures as high as 3000 °F.

The PCMTF provides industry and Government with a facility for studying the combustion process and for obtaining valuable test information on advanced materials. This report describes the facility's support systems and unique capabilities.

INTRODUCTION

Facilities for testing advanced combustors at high temperatures and pressures are in great demand. In order to provide advanced technical data for future aircraft materials and combustors, such facilities need to be able to handle combustion pressures up to 500 psig and temperatures up to 4000 °F inside the test chambers. This report discusses some of the unique features the Preheated Combustor and Materials Test Facility (PCMTF) offers for combustion and materials testing.

PCMTF SUPPORT SYSTEMS

The following section describes the support systems for the PCMTF. Table I summarizes the capabilities of these support systems.

Combustion Air and Altitude Exhaust Systems

The combustion air available for research purposes in the PCMTF has a pressure of 450 psig and a maximum flow rate of 30 pps. The dew point of the air is approximately -40°F ; this dew point is maintained with coolers and desiccants. A flow schematic of the facility is shown in figure 1. An isometric schematic of the facility is shown in figure 2. The air comes from a central station located in the basement of the Engine Research Building (ERB). It is filtered through a 10- μm filter assembly upstream of the main supply valve. Part of the air is then diverted to provide a secondary or dilution air source (fig. 1). Two valves control the airflow to the PCMTF; one is for high flow control, the other for low flow control. After flowing through either test stand, the air is vented to the atmosphere or to the altitude exhaust equipment. The altitude exhaust equipment can provide a back pressure vacuum equal to approximately 26 in. Hg (2 psia).

The nonvitiated combustion air can be heated to temperatures up to 1150°F by using a natural gas preheater. The preheater consists of four J-47 combustor cans and a counterflow heat exchanger. The shell side of the heat exchanger uses air at 1400°F (maximum temperature) and 40 psig, flowing at 15 pps (minimum flow), to heat the 450-psig tube-side air. The heated air can be routed to stand A or stand B. When one stand is in use, the other is sealed off by a blank flange. This eliminates any possibility of concurrent operation. A performance curve of the preheater is shown in figure 3. The shaded area under the curve represents combinations of nonvitiated airflow and temperature. Combustor inlet temperature and combustor airflow represent temperature and airflow conditions at the nonvitiated exit of the preheater.

Steam System

A steam system in the facility supplies heat to a steam-to-air heat exchanger. The system is rated for 340°F at 150 psi and has a maximum flow of 1200 lb/h (pph). The steam-to-air heat exchanger can heat the 450-psig combustion air that bypasses the preheater (fig.2), thereby allowing it to be used as secondary air or dilution air.

Cooling Water

The PCMTF can provide a maximum of 500 gpm of cooling water for research purposes. A schematic of the water system is shown in figure 4. The cooling water comes from cooling towers at approximately 50 psig into a 6-in. line in the basement. The water is nonpotable because it is treated with chemicals that retard rust in pipes. It is filtered and sent directly to two high-pressure pumps, a 500-psig pump and an 800-psig pump. The 500-psig pump supplies the primary exhaust spray cooling water for both A and B test stands as well as the research cooling water. The 800-psig pump supplies cooling water to test stand B, and with modification could supply stand A. Both test stands are supplied with 50-psig cooling water (low-pressure water), which is used for research hardware cooling and for secondary spray cooling of the exhaust gases exiting the facility. The cooling tower water that cools the test hardware and the water that condenses out of the exhaust gases are returned to the cooling towers through a dewatering system located in the basement of the ERB. An optional return line can be used to pump the water to the industrial waste system if the water is contaminated with fuel or hazardous chemicals. City water at 60 psig is also available in the PCMTF; it is used for laser and instrumentation cooling.

Fuel Systems

A 40-psig natural gas system heats the nonvitiated preheater. There are two other fuel systems available for the research programs: a liquid jet fuel system for aviation fuels such as Jet-A or JP-5, and a gaseous-hydrogen system. Either test stand may use either fuel system.

Liquid jet fuel system.—A schematic of the liquid fuel system is shown in figure 5. The liquid fuel is stored in a 5000-gal fuel tank with secondary containment in case of a spill or a leak. A 30-psig pump transfers the fuel from the tank to a high-pressure pump capable of providing 11 gpm of fuel at 900 psig. Control valves regulate the flow of fuel to the combustor. Several turbine flowmeters capable of measuring the full range of desired flows are also used. The unused fuel is passed through a water-cooled heat exchanger and returned to the fuel tank.

Gaseous-hydrogen system.—The gaseous-hydrogen system supplies high-pressure hydrogen to the test facility, as shown in figure 6. A schematic of the hydrogen system is shown in figure 7. This system is the only high-pressure, high-volume hydrogen system in the ERB. The hydrogen system has two parts, a high-pressure side (2400 psig) and a low-pressure side (500 psig). The high-pressure side consists of a 70 000-ft³ trailer located in a parking lot approximately 500 ft from the PCMTF, a flexible disconnect hose, two vent valves, and a shutoff valve. The low-pressure side consists of a control valve, shutoff valve, vent valve, critical flow venturi, and an orifice to measure flow. The flexible disconnect hose is used to join solid piping to the hydrogen trailer. A regulator is used to reduce the hydrogen pressure to 500 psig. In case of a major hydrogen line rupture in the cell, a 34 500-standard-ft³/min (SCFM) vent fan will keep the hydrogen-to-air mixture below the flammability limit. The vent fan always operates during testing in the facility. Also, there is a 100-psig nitrogen purge system for purging the line before and after each run.

DATA ACQUISITION, RECORDING, AND INSTRUMENTATION SYSTEMS

Escort and ESP Systems

The Escort D system (ref. 1) in the PCMTF is a MicroVAX-II-based data acquisition system that can measure steady-state temperatures, pressures, flows, and other physical parameters with an update rate of once per second. Escort can accept a millivolt input from a sensor and convert it to meaningful engineering units. Typical input devices are position potentiometers, strain gauge transducers, thermocouple oven outputs, and flowmeters. The system also communicates with a Pressure Systems Incorporated, Electronically Scanned Pressure (ESP) measurement system. Some steady-state pressure information for Escort is obtained through the ESP system. Major parts of the system are the host PC, the Data Acquisition and Control Unit (DACU), the Pressure Calibrate Unit (PCU), and the pressure modules. Each of the pressure modules in the system can measure up to 16 separate pressures in the same range. Each pressure measurement port in the module has its own strain gauge pressure transducer, which displays a voltage when a pressure is applied. The ESP system can maintain a 0.15-percent accuracy through its unique recalibration feature. The DACU controls the PCU and pressure modules, and calibrates the system every 20 minutes. The DACU commands the PCU to apply three calibration pressures to every port on each pressure module. Calibration pressures are measured by high accuracy Digiquartz transducers. The DACU, using the Digiquartz as a standard, generates conversion coefficients for every port and sends the conversion coefficients to the host PC. Additional pressure measurements can be obtained by using individual transducers. There are two main types of transducers used: Setra Systems Inc. transducers, which display a pressure based on a 0.0- to +5.0-V full-scale output; and strain-gauge-type transducers, whose output is routed through signal conditioners before the data are displayed.

The facility has four different types of thermocouples, which are shared by both test stands: the chromel/alumel ones (type K) have 264 channels; the 13% rhodium/platinum ones (type R) have 96 channels; chromel/constantan ones (type E) have 12 channels; and the copper/constantan ones (type T) have 12 channels.

Escort D provides real-time data acquisition as well as alphanumeric and graphic display pages. Test-dependent calculations can also be performed and displayed in real time. Hardcopy printouts of Escort display pages may be taken during testing. Data points are recorded to a fixed disk on the MicroVAX and then trans-

ferred to the NASA Lewis scientific VAX cluster. Data on the cluster are available for postrun analysis and processing through the VAX and other computers connected to the cluster.

Gas Analysis System

The facility has a gas analysis system, which uses a water-cooled, stationary (fixed position) probe to collect emissions data. From this information, the performance of the combustor may be evaluated. The system consists of a bank of emission analyzers (see table II) with which to properly analyze products of combustion.

OVERHEAD CRANE

Spool pieces are installed and removed from both test stands with a 2-ton crane. It can span both test stands in any direction. There is also a smaller, 1/2-ton, crane. This smaller crane functions as an extension of the main crane for transporting hardware past the two exhaust sections of the A and B test stands.

FACILITY SAFETY FEATURES AND PRECAUTIONS

Each test stand has many safety interlocks to prevent the occurrence of potentially unsafe or destructive conditions. A Modicon 984-680 Programmable Logic Controller with ladder logic (which allows programming of permissives, shutdowns, and delay timers) automatically takes action if a dangerous situation occurs. In addition, the PCMTF, which includes the preheater, fuel systems, and exhaust systems, has several safety interlocks to prevent an unsafe or destructive condition. If an unsafe condition should occur, such as a power failure, the PCMTF facility control logic will go into a safe mode by shutting off the fuel, isolating the high-pressure systems, and opening the vents to avoid any overpressure situations. Alarms will then sound, thereby warning the operator of an unsafe condition.

Sniffers are used to detect leaks in the hydrogen system and natural gas lines that go to the preheater. During an emergency, the hydrogen system can be isolated from other systems with a block-and-bleed system. In the event of a Modicon controller failure, there is a hydrogen shutoff valve that is wired directly to a push button on the control panel. This button provides power to operate the valve.

Thermocouples attached to the preheater wall cause an automatic shutdown of the preheater if any thermocouple senses a temperature above 1400 °F; this prevents damage from overpressure. To avoid any overpressure in the facility, the main exhaust valves are programmed such that the 450-psig supply air must be shut down before the main exhaust valves can be closed. In case of a power failure, the 450-psig supply valves and exhaust valves will remain in their last position. In addition to these features, there are several controls on each test stand so that each test rig can go to a safe mode during an emergency. When situations are less critical, such as low cooling pressure or a high water level in the sump, audible and visible alarms warn the operator of a possible unsafe condition. If a shutdown should occur, an audible signal is triggered and some action is taken to eliminate a dangerous condition. The alarms and shutdown indicators are mounted on panels inside the control room, which is shown in figure 8.

CONCLUDING REMARKS

The Preheated Combustor and Materials Testing Facility has been operating in the Engine Research Building for over 35 years. The test information obtained from it has been used to develop combustor liner

materials for future jet engines and to gain a better understanding of subsonic combustion. The capacity of the preheater, the capability for high-pressure air, the supply of nonvitiated air, and the availability of a wide range of fuels—from hydrogen to Jet A—make it a most appropriate facility for testing advanced aircraft engine components.

REFERENCE

1. Fronek, D.L., et al.: A Distributed Data Acquisition System for Aeronautics Test Facilities. NASA TM-88961, 1987.

TABLE I.—PCMTF SUPPORT SYSTEMS CAPABILITIES

	Supply air (total)	Natural gas preheater	Steam	Cooling water	Fuel	
					Hydrogen	Aviation fuels
Flow rating	33 lb/s	600 ft ³ /min	1200 lb/h	500 gal/min	0.125 lb/s	11 gal/min
Pressure rating	450 psig	50 psig	150 psig	45 psig 500 psig 800 psig	500 psig	900 psig

TABLE II.—GAS ANALYSIS SYSTEM EMISSION ANALYZERS

Gas	Analyzer	Detection mode	Sensitivity	Precision
NO	Rosemount Analytical Model 955	Chemiluminescent reaction of NO and O ₃	0 to 10 000 ppm	<0.5
NO _x	Thermo Electron Model 10A	Chemiluminescent reaction of NO and O ₃	0 to 10 000 ppm	<1.0
CO	Rosemount 880	Infrared radiation	0 to 15 percent	1.0
CO ₂	Rosemount 880	Infrared radiation	0 to 20 percent	1.0
H _x C _x	Rosemount 44	Flame ionization	0 to 10 000 ppm	1.0
O ₂	Rosemount 755	Polarographic sensor	0 to 25 percent	1.0

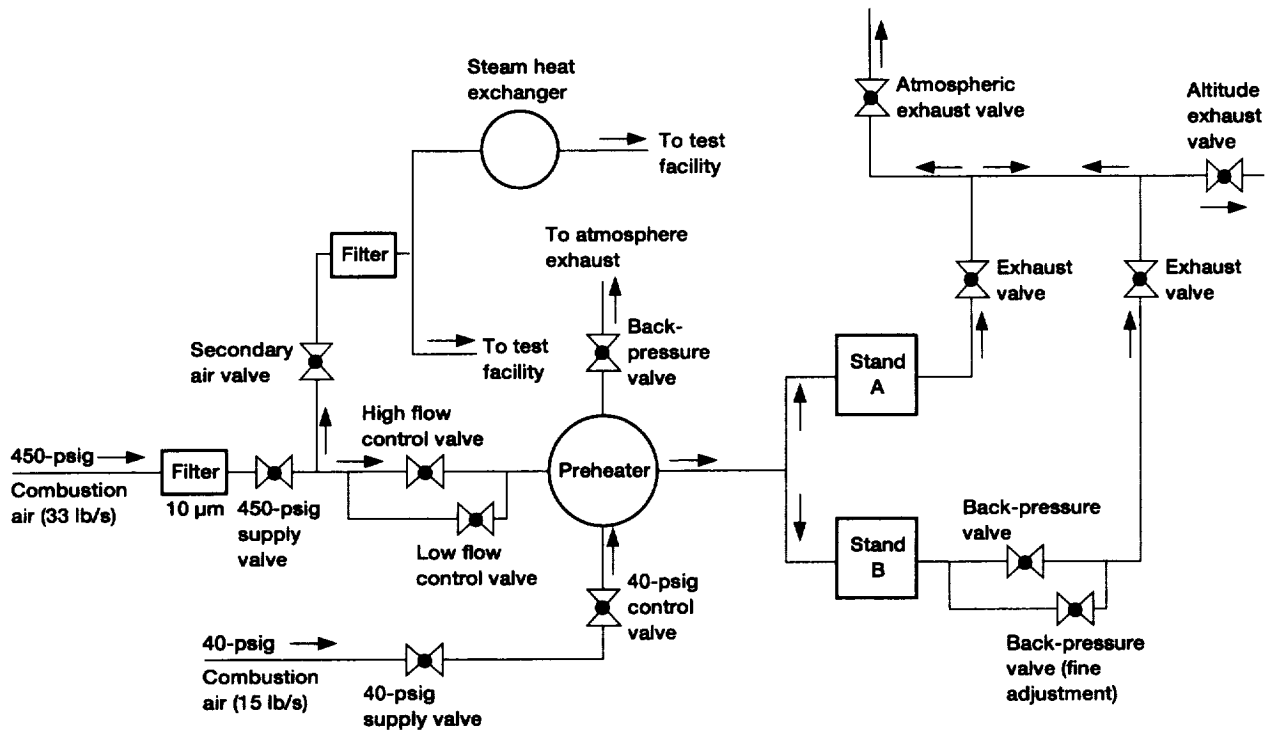


Figure 1.—Combustion airflow in Preheated Combustor and Materials Test Facility (PCMTF).

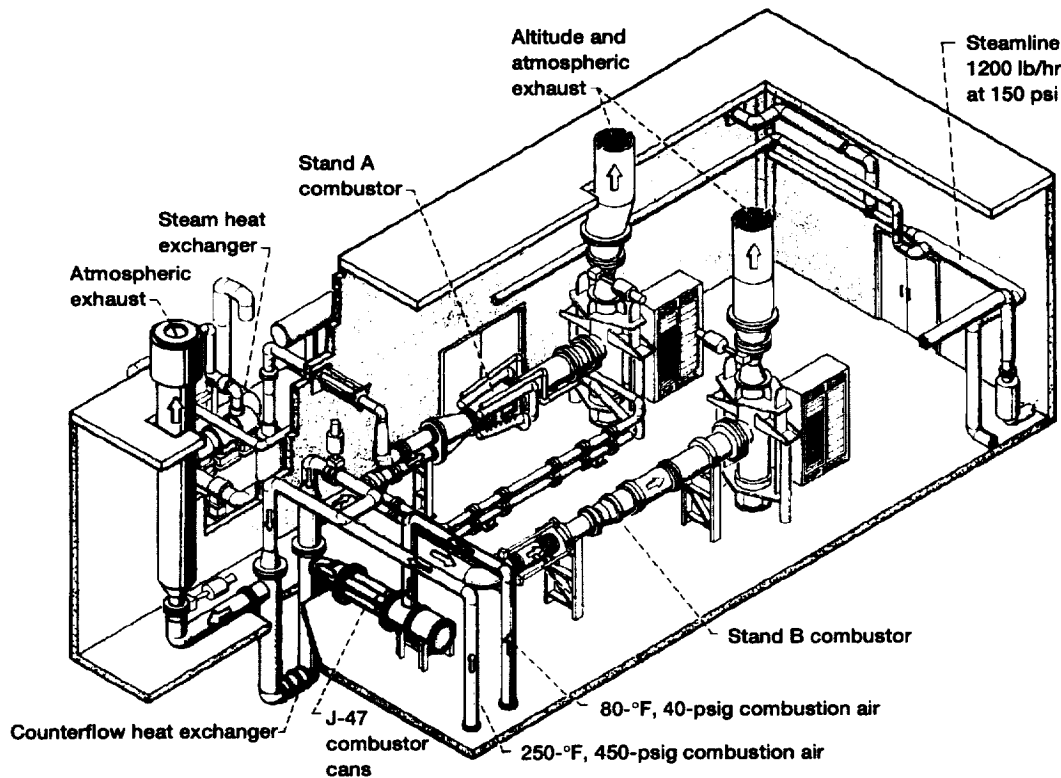


Figure 2.—PCMTF schematic.

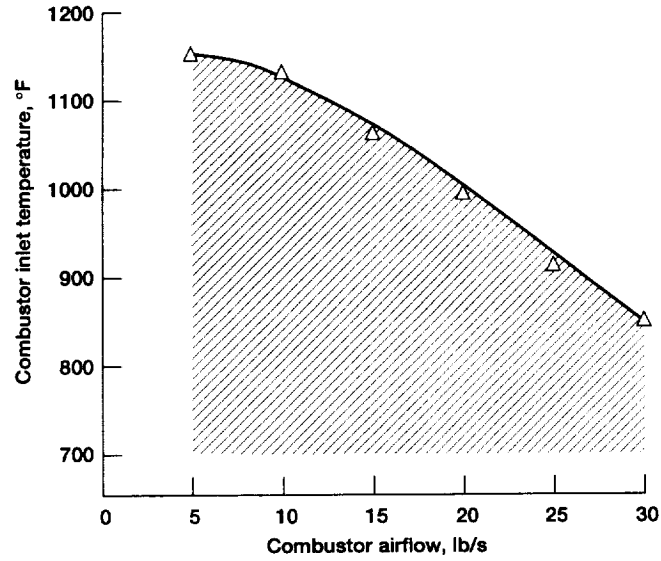


Figure 3.—Heat exchanger performance for the PCMTF (preheater inlet temperature = 250 °F; preheater shell temperature = 1400 °F).

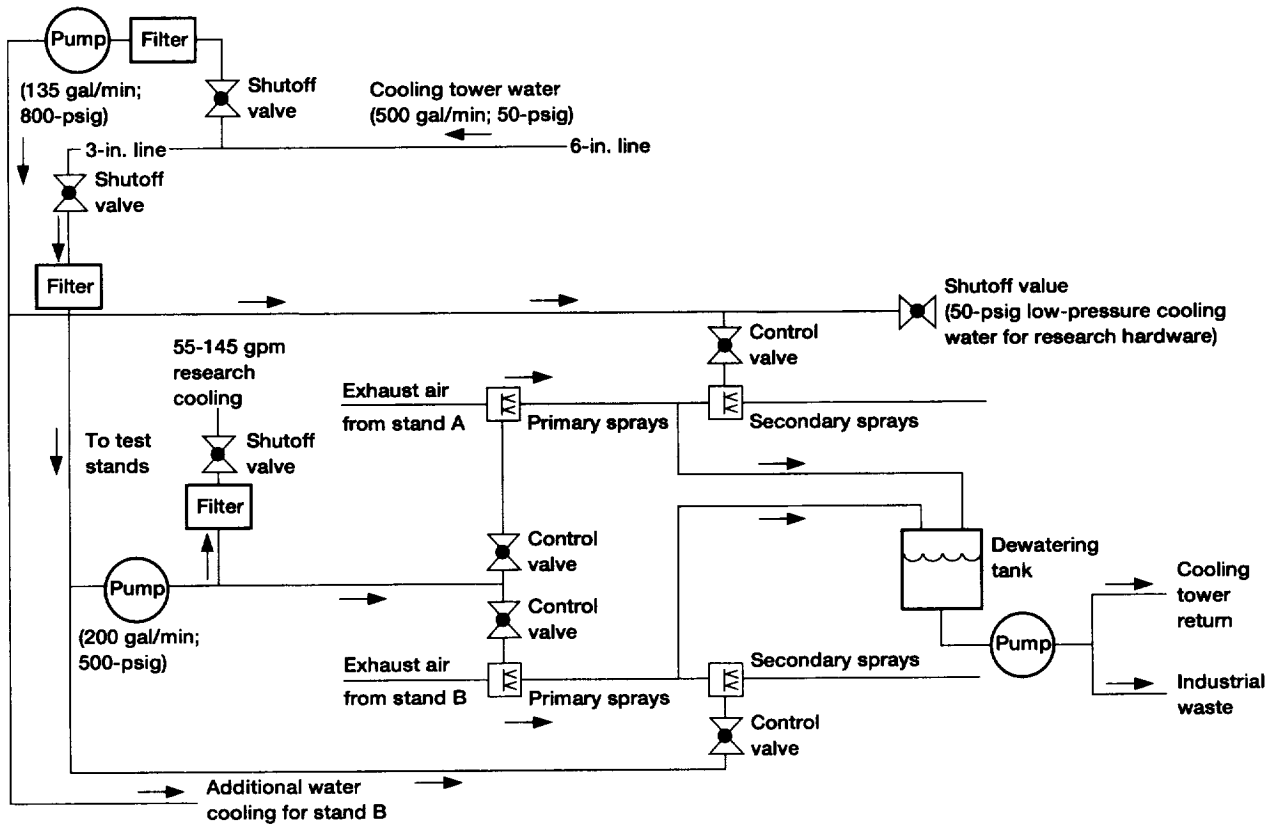


Figure 4.—Cooling water system.

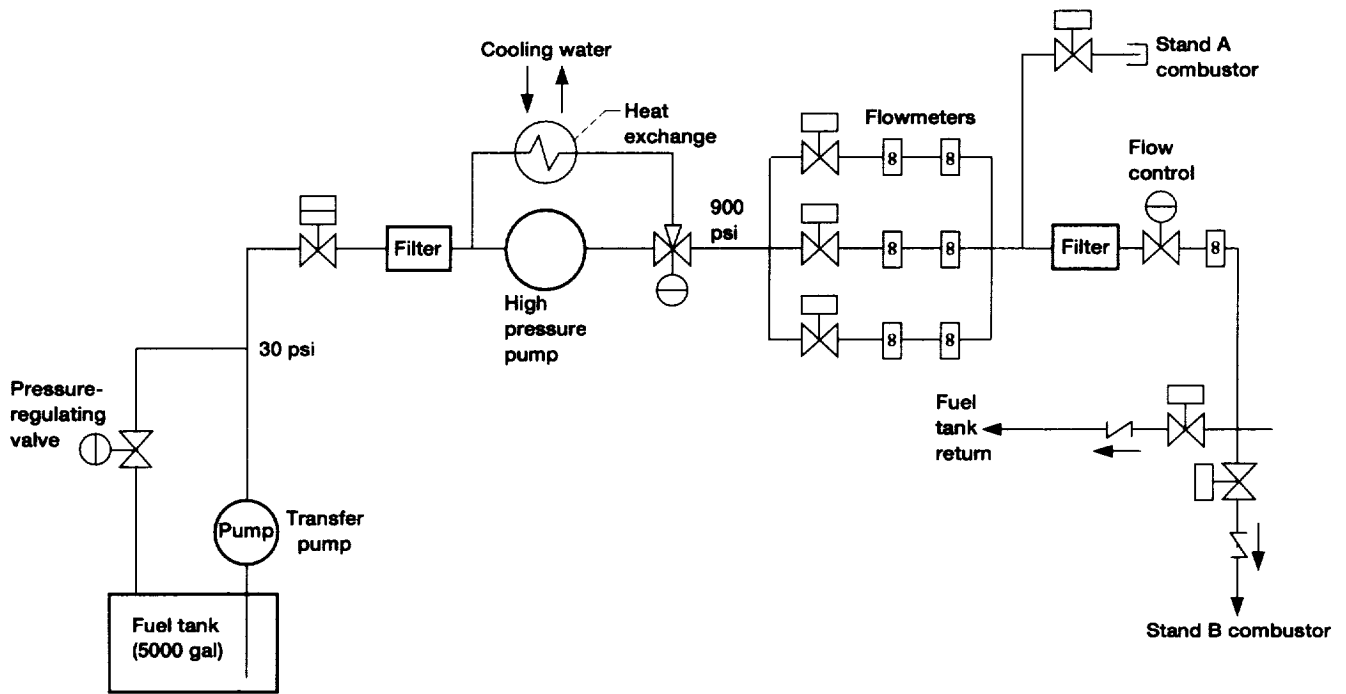


Figure 5.—Liquid fuel system.

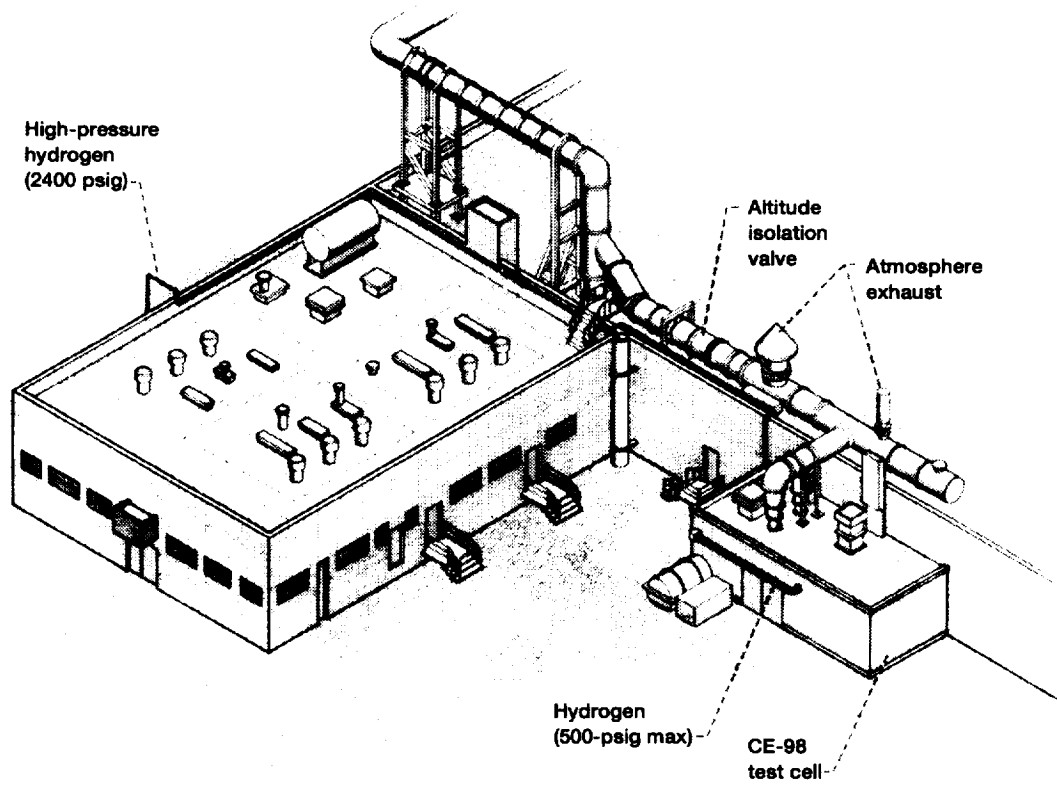


Figure 6.—Hydrogen supply system.

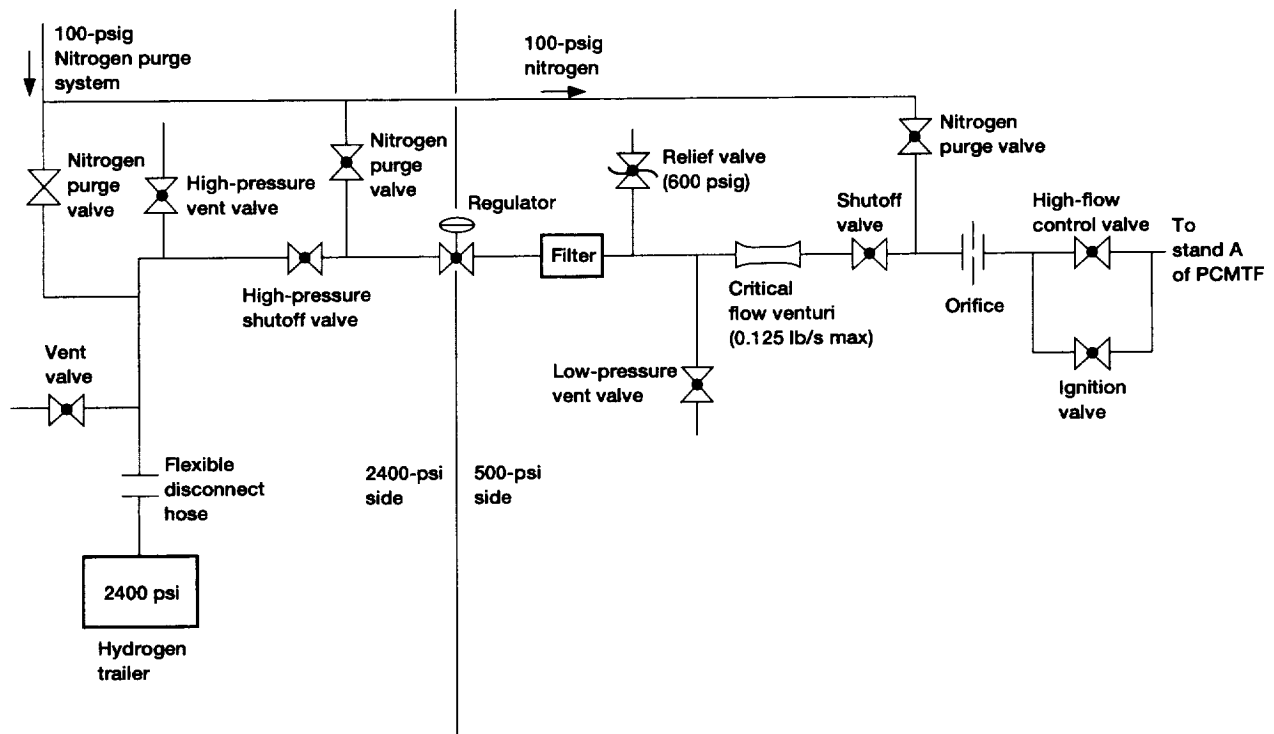


Figure 7.—Hydrogen system schematic.



Figure 8.—Control room of the PCMTF.

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